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TOTAL ELECTRON CONTENT VARIATIONS AT MID-AND-HIGH-LATITUDES. (U)
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RESEARCH AND DEVELOPMENT TECHNICAL REPORT

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TOTAL ELECTRON CONTENT VARIATIONS AT MID-AND-HIGH-LATITUDES

H. SOICHER
F. J. GORMAN
COMMUNICATIONS SYSTEMS CENTER

JANUARY 1982

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Total electron content (TEC) observations were made at various midlatitude and high latitude stations using beacon satellite emissions from geostationary satellites. The Faraday rotation technique was utilized in making TEC Measurements during the periods near the minimum and maximum of the current solar cycle. Latitudinal, seasonal, and solar-cycle dependence of TEC were observed with seasonal effects being most consistent. Day-to-day variability of TEC, as expressed by the ratio of the monthly standard deviation of TEC to TEC was found to be 25% for the daytime period irrespective of station position, season or solar cycle		

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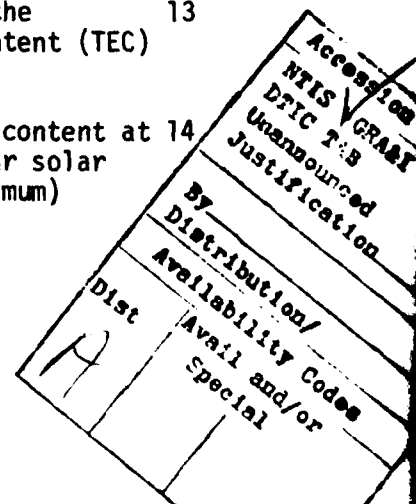
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TOTAL ELECTRON CONTENT VARIATIONS AT MID-AND HIGH-LATITUDES

INTRODUCTION

Total electron content (TEC) measurements at various sites have been made by monitoring the polarization rotation of VHF transmissions from geostationary satellites during the final portion of the last solar cycle (number 20) and continuing into the present solar cycle (number 21). Depending on the available satellite beacon sources, measurements have been taken at Fort Monmouth, NJ (40.18°N, 74.06°W), Richmond, FL (25.60°N, 80.40°W), White Sands Missile Range, NM (32.36°N, 106.41°W), Anchorage, AK (61.04°N, 149.75°W), Kiruna, Sweden (61.84°N, 20.41°E), and Haifa, Israel (32.87°N, 35.09°E). The observations of the polarization rotation have provided measurements of the total (integrated) electron content (TEC) along the ray path (however, they have been normalized in this paper to the vertical direction) by means of the Faraday rotation technique. Since Faraday rotation is dependent on the Earth's magnetic field, and since its magnitude is heavily weighted near the Earth, it is considered to provide integrated total electron content values for altitudes below 2000 km. During the period of observations the smoothed average monthly sunspot number (SSN) varied from 12 to 190. In this paper the variation of the total electron content will be compared at the various stations during the minimum of the solar cycle, and the data at Fort Monmouth, NJ will be compared at the minimum and maximum of the solar cycle.

THE DATA

The superimposed diurnal variation of the TEC at Fort Monmouth, NJ for September 1979 is shown in the upper part of Figure 1. Since the total electron content proportionately delays a traversing signal, also indicated in the figure is the excess time delay (in nanoseconds) that a 1.6 GHz signal (in the satellite navigation band) would experience. The normal diurnal variation is exhibited as is the day-to-day variation. The data is evaluated at 15-minute intervals. The monthly average as well as the monthly standard deviation for September, 1979 are shown in the lower part of Figure 1.

The hourly values of the monthly averages of TEC for Richmond, FL during August through December 1976 (SSN 14) are shown in Figure 2. Maximum TEC values are attained during the equinoctial months (September-October), while minimum values are attained during winter (December). The daytime monthly average gradually increases from July to October and then gradually decreases to December. The nighttime monthly averages exhibit a different trend with September being the lowest in TEC value while gradual increases are observed from September to December.

Since the sunspot number is nearly fixed this figure typifies the seasonal variability of the TEC, i.e., the daytime absolute value of TEC decreases gradually from its maximum at the equinox.

A predawn increase in TEC for all months is clearly observed in the data. This increase has been explained in terms of ionospheric-plasmaspheric coupling (1, 2). Differences in the rate of buildup and decay of the TEC are observed for the various months.

The hourly values of the monthly averages of TEC for White Sands Missile Range, NM during July through November 1977 (SSN variability from 29 to 52) are shown in Figure 3. Again, TEC maximizes in October, it increases gradually from July to October from whence it decreases. However, when compared to the Florida data in Figure 2 one sees the effect of SSN variation. While in Florida during the daytime TEC is higher in August than in November, in White Sands TEC is higher in November than in August. This may be attributed to the nearly 50% increase in sunspot number. As in the Florida data a predawn increase in the TEC is observed.

The hourly values of the monthly averages for Haifa, Israel during October 1975 through August 1976 (SSN 15) are shown in Figures 4 and 5. Two relative maxima in TEC are observed; one in the equinoctial period of March-April and the other in the equinoctial period October, with TEC being higher in the former. Daytime TEC decreased gradually from October to January, increased gradually from January to April, from where it declined gradually to July increasing again to August. Again, since the sunspot number remained nearly constant throughout the whole period, the variation indicates the daytime seasonal variability of the data i.e. maxima at the equinoxes and minima at winter and summer. Predawn increases are observed for the equinoctial periods only.

Turning to the high latitude, the hourly values of the TEC monthly averages for Anchorage, AK (SSN 14) and Kiruna, Sweden (SSN 16) are shown in figures 6 and 7 respectively. The same seasonal variation exhibited for the temperate latitude stations is exhibited for the high latitude stations, i.e., maximum daytime values during October and gradual decline from there (although in Anchorage January daytime values exceed those for December). The predawn TEC increase is more pronounced in Anchorage than in Kiruna. Despite the similarity of the latitudinal position of the two stations and the fact that the periods of observation, although a year apart, are during same months for nearly equal sunspot numbers, the winter values at Anchorage are higher than corresponding Kiruna values. This may be due to the fact that Kiruna is at a higher geomagnetic latitude (about 3°)

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1. P. R. Arendt and H. Soicher, "Downward Electron Flux at 1000 km Altitude from Electron Content Measurements at Mid Latitudes", Nature 204, 983, 1964.
 2. J. V. Evans, "Cause of the Midlatitude Winter Night Increase in f_oF_2 ", Journal of Geophysical Research 70, 4331, 1965.

and/or due to the relative position of the high latitude trough especially at night, at the two locations (3,4).

Figure 8 summarizes the previous figures by showing the maximum and minimum values of the TEC monthly averages for all stations for all reported times. The seasonal, latitudinal and time variability is clearly exhibited.

The day-to-day variability of the total electron content is of interest scientifically and of great importance in assessing TEC prediction capabilities. In the latter it expresses the expected accuracy of the daily predictions if monthly averages could be predicted. The ratios of the monthly standard deviation of TEC to the absolute value to TEC as a function of local time (for comparison purposes) for all the stations are shown in Figure 9. The significance of the results depicted in the figure is the fact that during the day the ratios are 25% (5). The ratio is significantly higher at night especially during the equinoctial period (see the October curves for Kiruna, Fort Monmouth, Anchorage and Richmond). The day-to-day nighttime variability is thus not sufficiently reduced when compared to the daytime variability to offset the sharply lower absolute values of TEC during the night as compared to those during the day.

The comparison of hourly values of the TEC monthly averages at Fort Monmouth, NJ for the equinoctial (September, October) and winter (December, January) periods during the minimum (1974, 1975) and maximum (1979, 1980) epochs of the solar cycle are shown in Figures 10, 11, respectively. The sunspot number increased approximately by a factor of six; the corresponding increase for maximum TEC values was threefold for the equinoctial period and fivefold for the winter period. The seasonal variation is independent of the sunspot numbers, i.e., equinoctial TEC values are maximum while winter values are minimum during both periods.

The ratios of the monthly standard deviation to the absolute value of TEC for Fort Monmouth for the equinoctial and winter periods during the minimum and maximum of the solar cycle are shown in Figure 12. Again, during the day the ratio is 25%. During the night the ratio may be significantly higher.

-
3. D. B. Muldrew, "F-Layer Ionization Troughs Deduced from Alouette Data", Journal of Geophysical Research 70, 2635, 1965.
 4. L. Liska, "The High Latitude Trough in the Ionospheric Electron Content", Journal of Atmospheric and Terrestrial Physics 29, 1243, 1967.
 5. J. A. Klobuchar, "Ionospheric Effects on Satellite Navigation and Air Traffic Control Systems", AGARD Lecture Series No. 93 on "Recent Advances in Radio and Optical Propagation for Modern Communication, Navigation and Detection Systems", (AGARD-LS-93), 1978.

CONCLUSIONS

Total electron content data taken at diverse temperate and high latitude stations show the following common and special characteristics:

1. Seasonal variability of the data is independent of the location of the station and the phase of the solar cycle. Daytime TEC values maximize at the equinoctial periods, and minimize at the winter and summer periods. Nighttime values of TEC generally follow the trend of the daytime values, with some exception, however.

2. When average sunspot numbers are nearly constant over long periods of time the seasonal variability is dominant. Rapidly varying sunspot numbers may alter the seasonal variability.

3. The ratios of the monthly standard deviation to the average TEC during daytime periods appear to be independent of the station location and the phase of the solar cycle. The daytime ratio is 25%. At the nighttime periods the ratio may be quite erratic especially during equinoctial periods.

4. Sunspot number control of TEC is quite apparent, with TEC increasing in proportion to sunspot numbers. The proportionality of TEC increase is seasonally dependent. It appears to maximize for the winter period (when TEC values are relatively lower) and minimize during the equinoctial period (when TEC values maximize).

5. High latitude stations at similar latitudes but with wide longitudinal separation have different TEC values during periods of similar sunspot numbers. This may be due to the relative location of the high latitude trough, a region of reduced ionization, and/or due to difference in geomagnetic coordinates.

6. Predawn nightly increases of TEC are observed. They are indicative of ionization transport between the ionosphere and plasmasphere.

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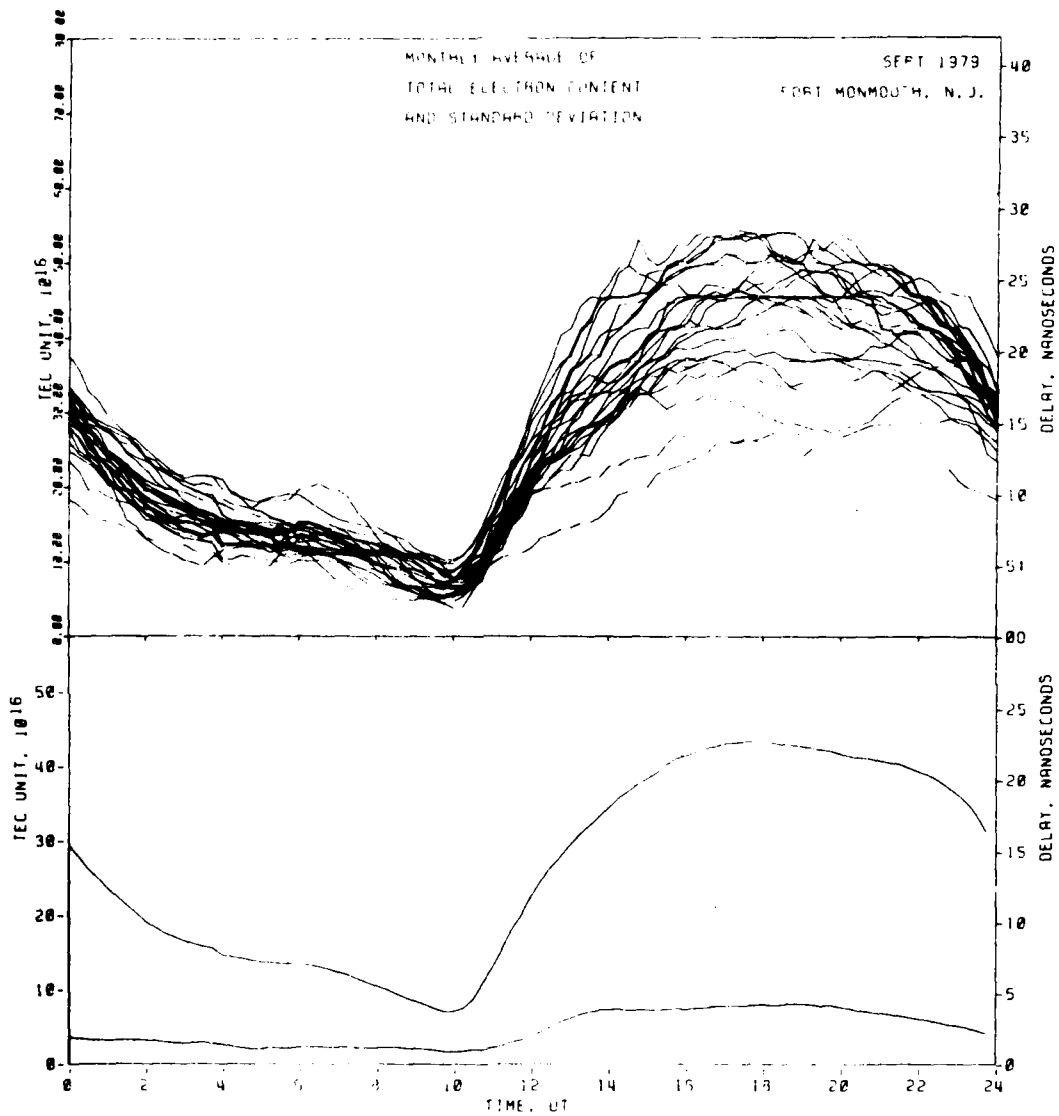


FIGURE 1 Daily, monthly average, and standard deviation variations of total ionospheric electron content

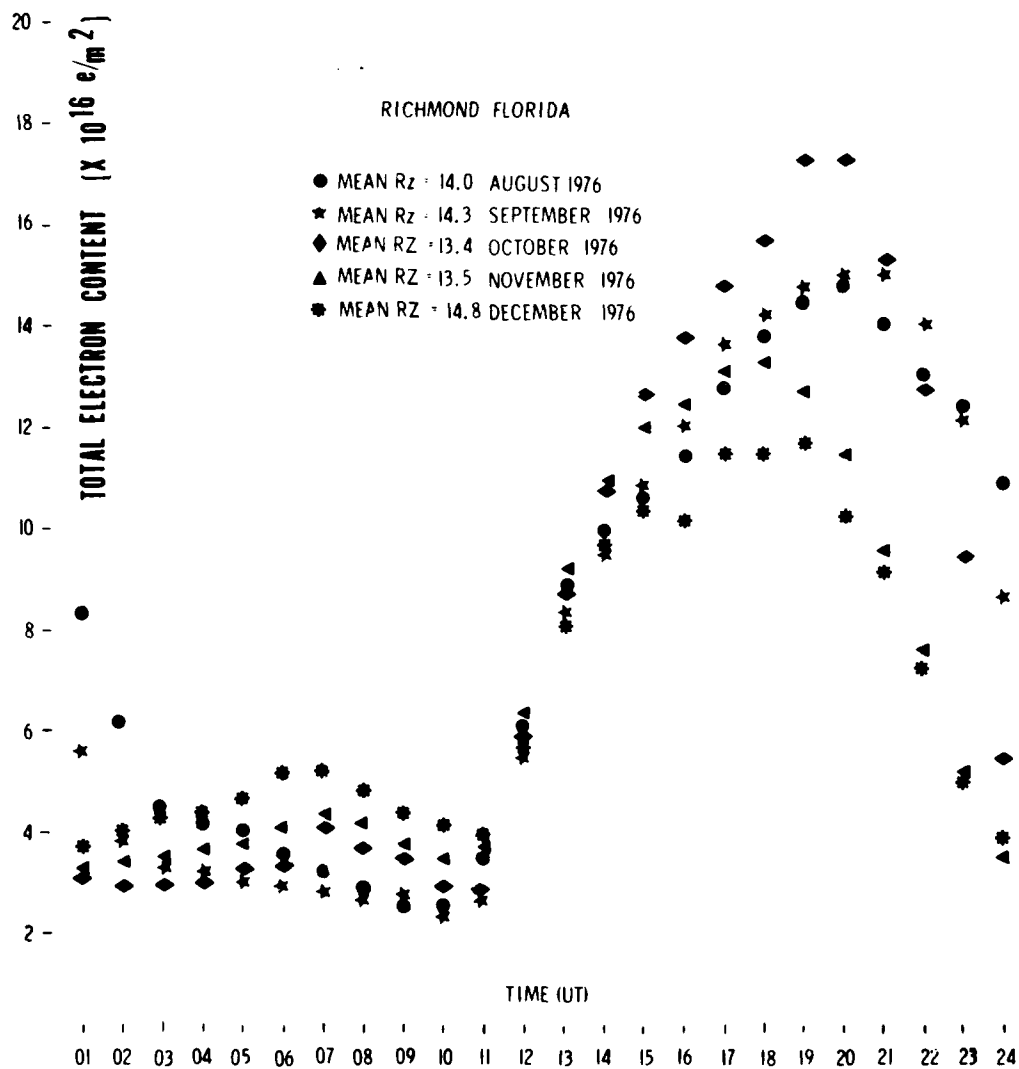


FIGURE 2 Monthly average diurnal variability of total electron content at White Sands Missile Range, NM

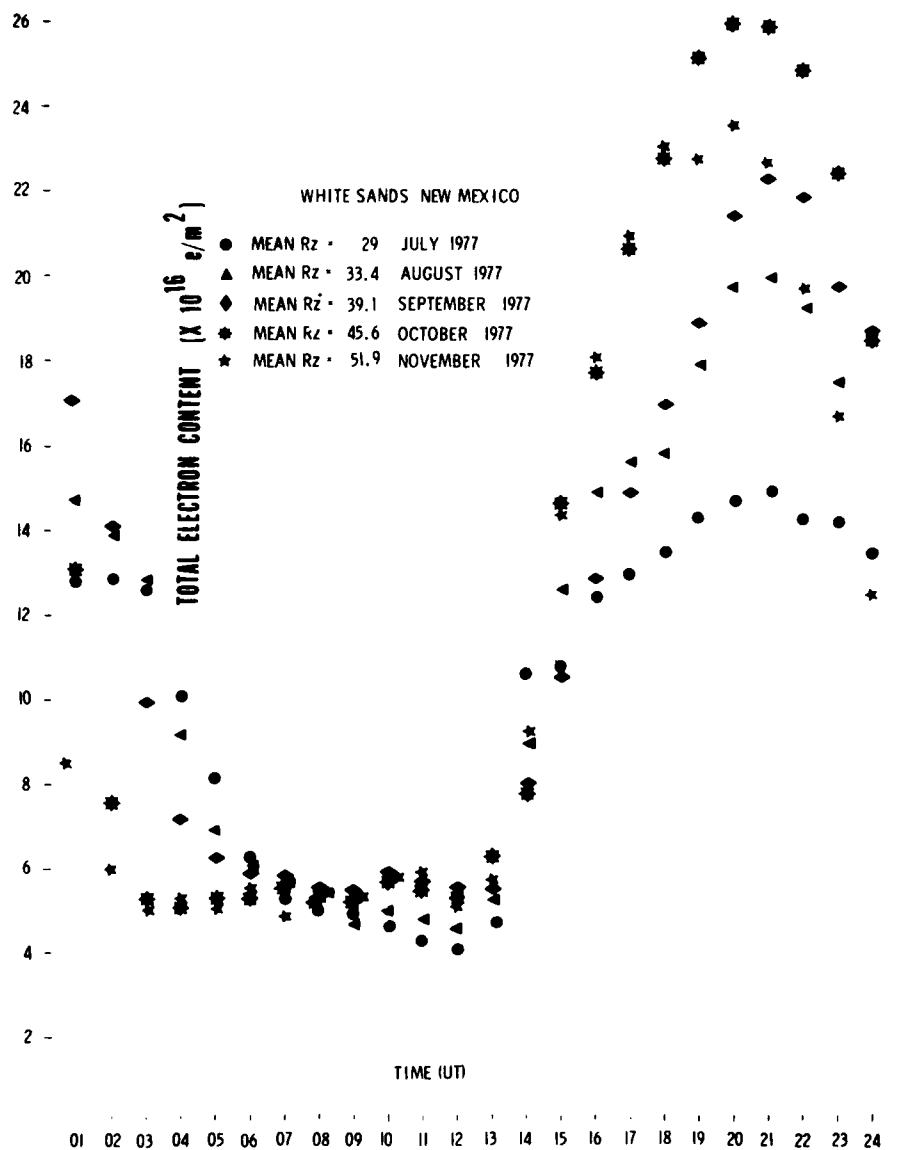


FIGURE 3 Monthly average diurnal variability of total electron content at Richmond, FL

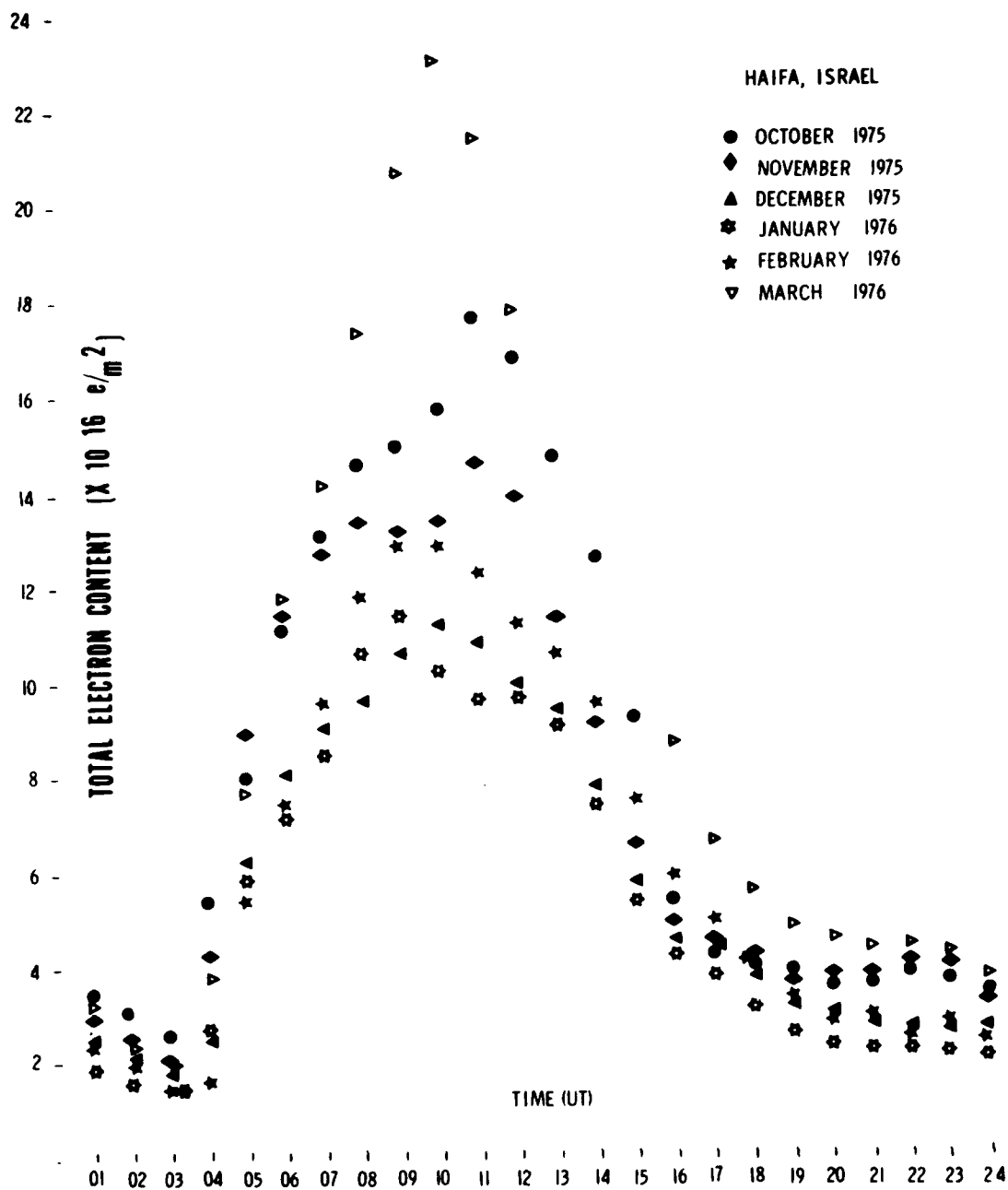


FIGURE 4 Monthly average diurnal variability of total electron content at Haifa, Israel (October 1975 through March 1976)

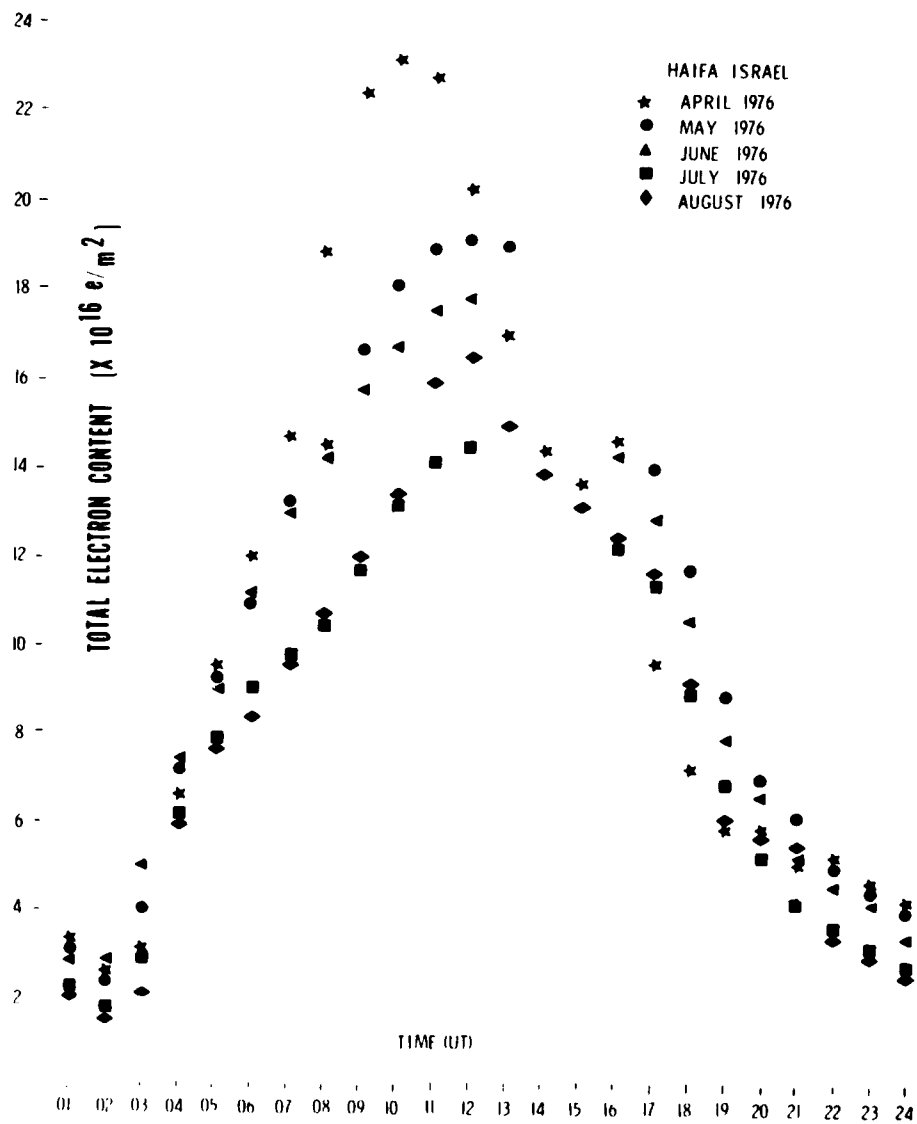


FIGURE 5 Monthly average diurnal variability of total electron content at Haifa, Israel (April through August 1976)

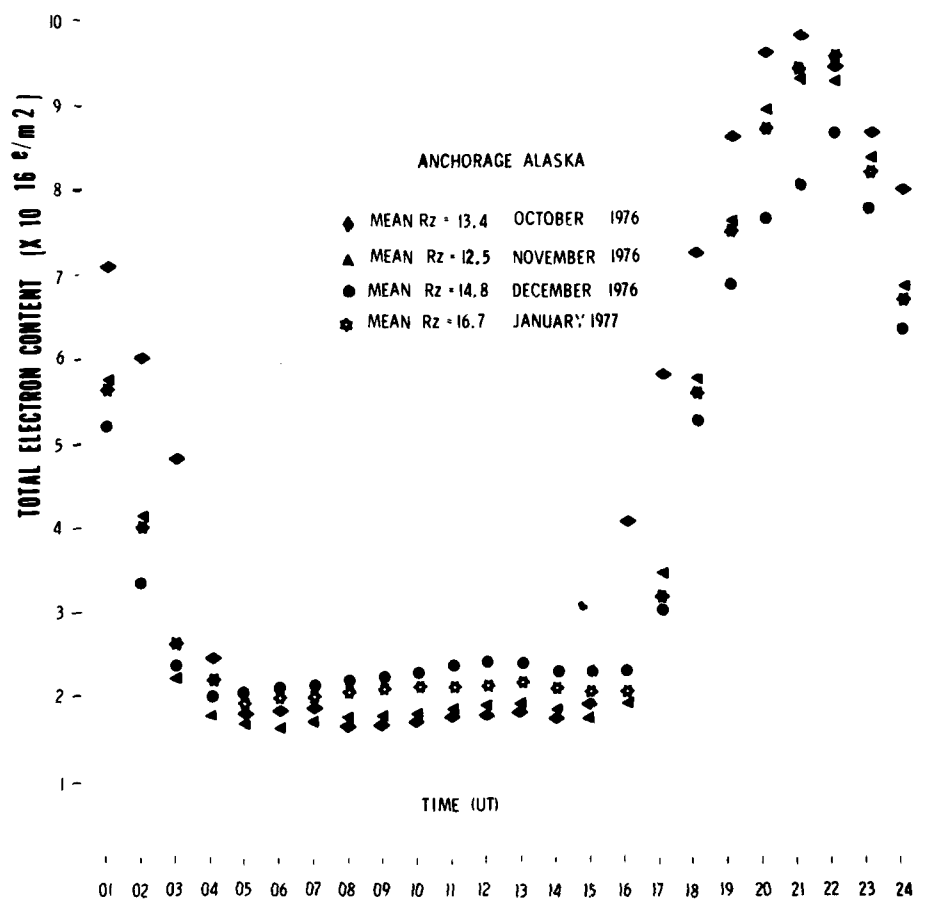


FIGURE 6 Monthly average diurnal variability of total electron content at Anchorage, AK

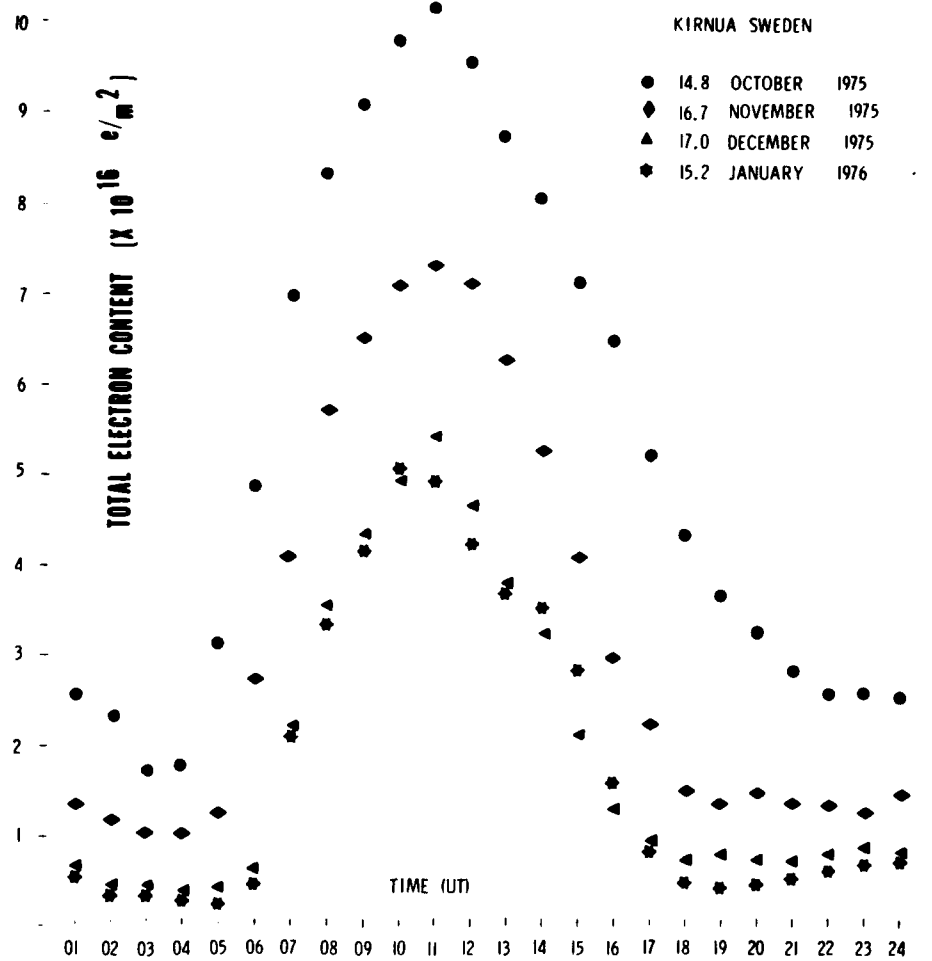


FIGURE 7 Monthly average to total electron content diurnal variability at Kiruna, Sweden

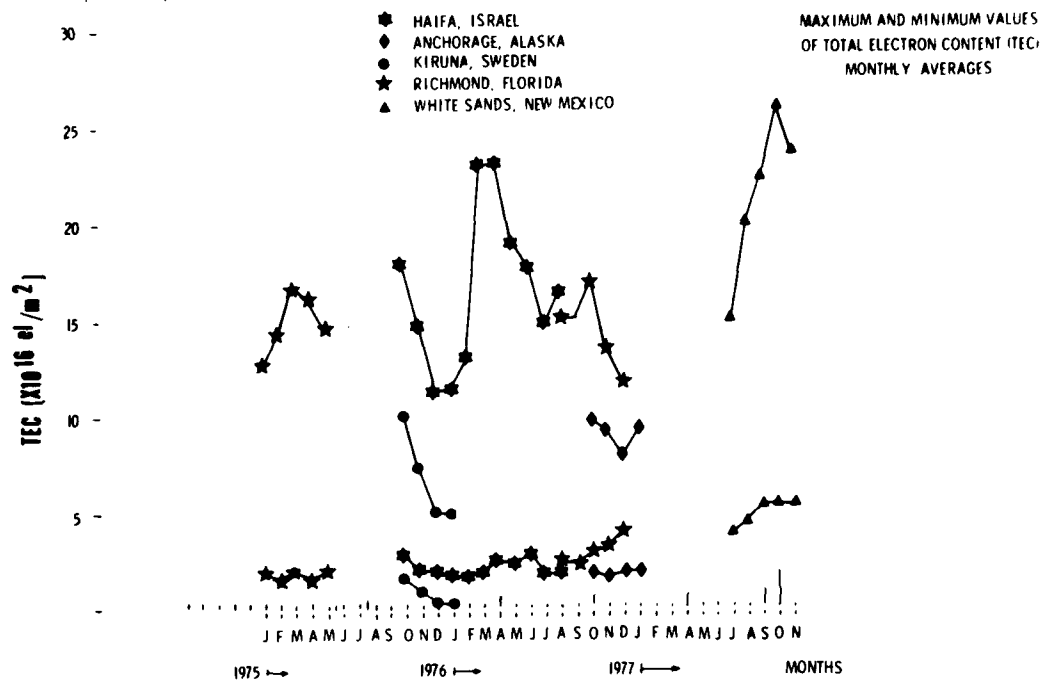


FIGURE 8 Maxim (daytime) and minimum (nighttime) value values of the monthly average total electron content values at various locations and months.

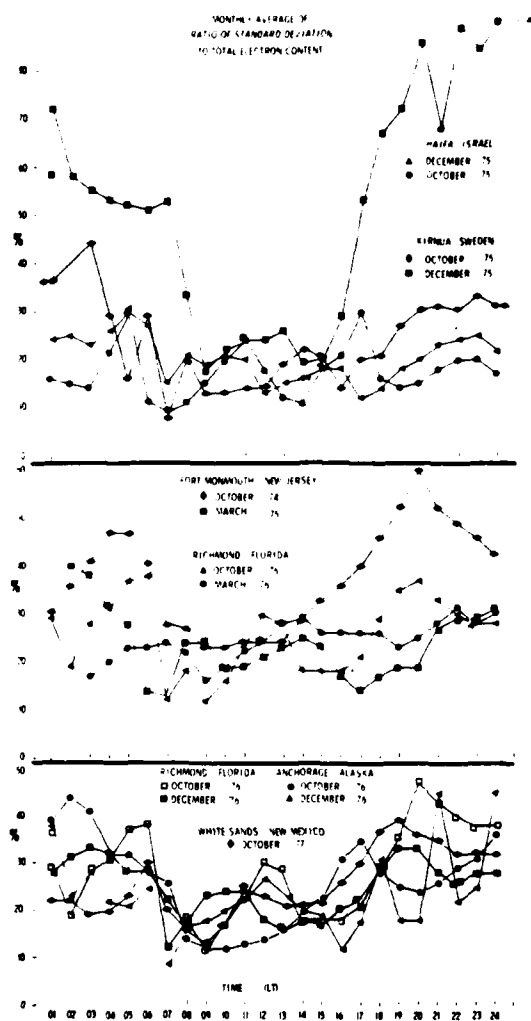


FIGURE 9 The diurnal variation of the ratio (in percent) of the monthly standard deviation of the total electron content (TEC) to the TEC at various locations.

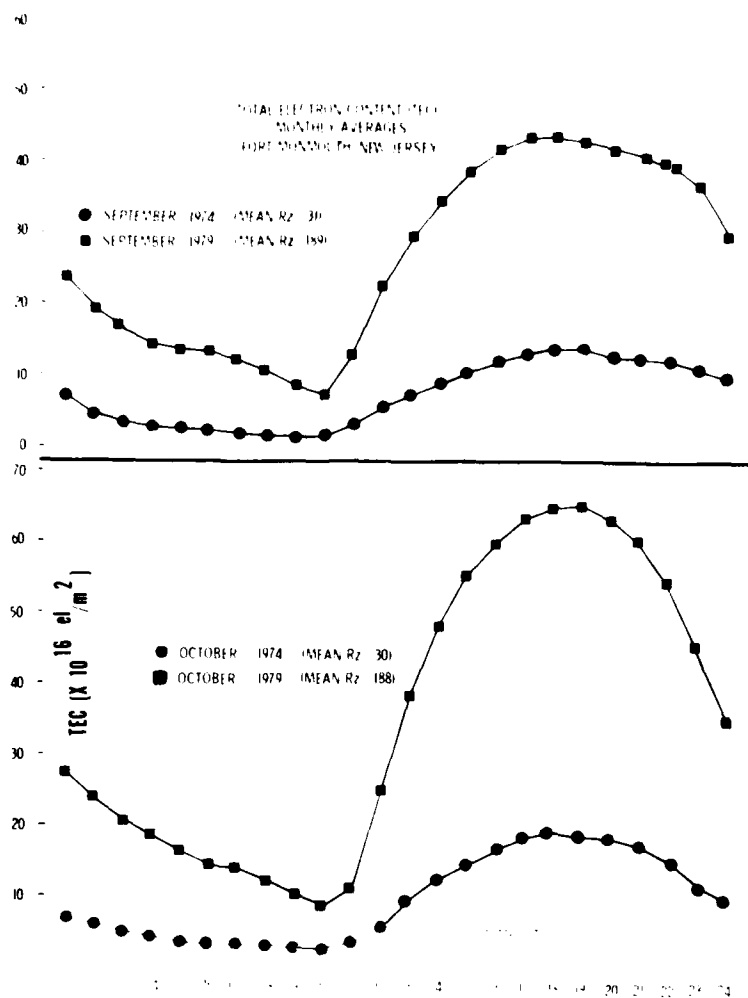


FIGURE 10 Monthly average diurnal variation of total electron content at Fort Monmouth, NJ during Sept-Oct 74 (near solar minimum) and Sept-Oct 80 (near solar maximum)

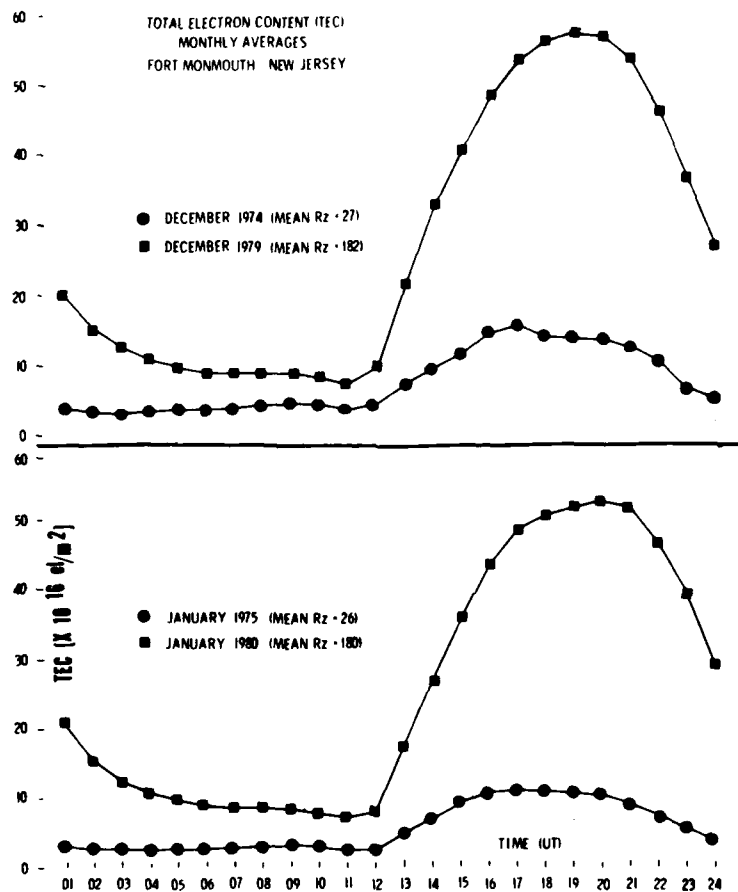


FIGURE 11 Monthly average diurnal variation of total electron content at Fort Monmouth, NJ during Dec 74 - Jan 75, and Dec 79 - Jan 80.

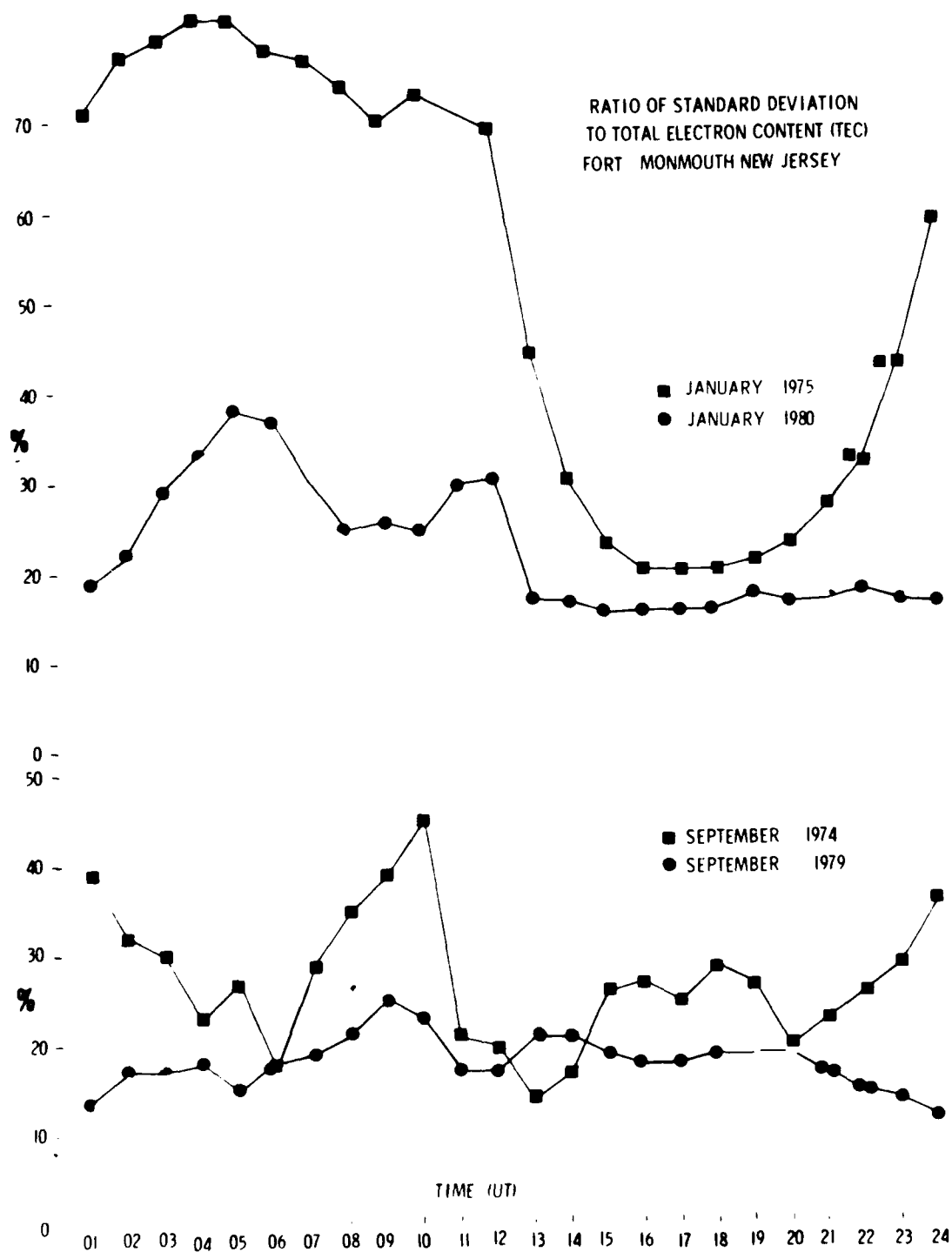


FIGURE 12 The diurnal variation of the ratio (in per-cent) of monthly standard deviation of the total electron content (TEC) to the TEC at Ft. Monmouth, NJ for Sept 74, 79 and January 1975, 1980.